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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Viscosity and
Viscosity Index

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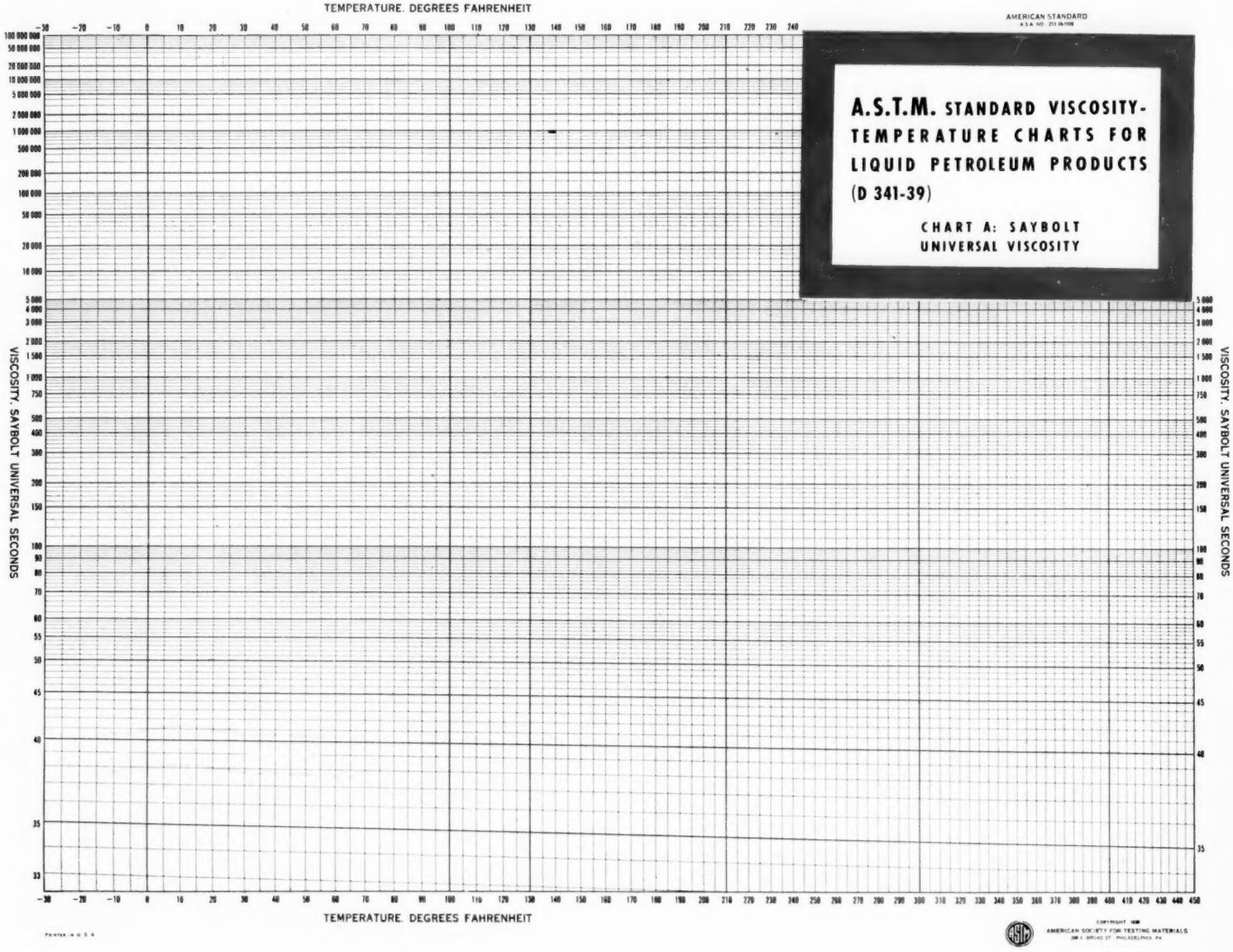
TEMPERATURE, DEGREES FAHRENHEIT
AMERICAN STANDARD
A.S.T.M. STANDARD VISCOSITY-TEMPERATURE CHARTS FOR LIQUID PETROLEUM PRODUCTS (D 341-39)
CHART A: SAYBOLT UNIVERSAL VISCOSITY
VISCOSITY, SAYBOLT UNIVERSAL SECONDS
TEMPERATURE, DEGREES FAHRENHEIT
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LUBRICATION

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Viscosity and Viscosity Index

PETROLEUM is the origin of products of varying fluidity all the way from gasoline to asphalts. The yardstick of their fluidity is viscosity. By use of this yardstick as a scale by which to measure the flow characteristics, the necessity for comparing individual samples is eliminated.

The physicist defines viscosity as a measure of the relative fluidity of a liquid at some specific temperature. As it is a relative measurement it must have some standard as a basis of comparison. The chemist chose pure water. Then he devised a meter for measuring viscosity, involving an orifice of precise dimensions. As temperature affects the fluidity of petroleum oils, he also had to establish standards of temperature. Then he arbitrarily chose a measured volume of oil for test purposes.

In the United States this resulted in the Saybolt Universal Viscosimeter. In England, the Redwood instrument; on the Continent, the Engler device.

Pure water is a handy reference fluid for standardization as it does not change appreciably in viscosity or relative fluidity between 32° F. (its freezing point) and 212° F. (its boiling point).

VISCOSITY

Viscosity, or body of an oil, as it is more generally understood by the average operator, is a measure of its relative fluidity at the temperature at which the viscosity is determined. Viscosity denotes internal fluid friction, or the extent to which flow is retarded due to the resistance which the molecules of an oil offer to flow past one another when the oil is in motion. Viscosity is possessed by all lubricating oils to a varying degree, it is controlled by the procedures used in refining.

VISCOSITY INDEX

Viscosity index is a calculated value based on known viscosities at 100° and 210° Fahr., indicating the rate of change of the viscosity of a petroleum lubricating oil with temperature.

A Valuable Control Test

Viscosity is a valuable control test in the oil refinery. When machine design and the automotive engine indicated the need for lubricating oils of varying fluidity (early in this century) knowledge obtained by viscosity measurements enabled the petroleum refiner to produce such oils. With a variety of oils available, the machine and engine builder then could investigate bearing loads, vary his operating temperatures, and go beyond conventional babbitt metals in planning his bearings. For high temperatures at all speeds and heavy loads at low speeds, he resorted to heavy or high viscosity oils. Conversely, for high speeds, lower temperatures and light loads, as with spindles, he chose more fluid oils.

Its Meaning and Application

The viscosity test has proved of value as a means of estimating the physical ability of a lubricating oil to maintain lubrication under any set conditions of operating speed, pressure and temperature. It is of distinct importance to have a clear understanding of this test in view of the relation of fluid or internal friction to power consumption. Obviously, reduction of fluid friction will reduce power consumption.

Viscosity will vary inversely with temperature, i.e., the colder an oil the heavier or more sluggish

will it become. As the temperature is raised, the same oil will become more and more fluid.

In the United States viscosity is measured commercially by observing the time required for a predetermined quantity of oil, i.e., 60 cc., to flow through an orifice of standard size under standard temperature conditions. The Saybolt Universal Viscosimeter and the Saybolt Furol Viscosimeter have been adopted for commercial purposes by the American Society for Testing Materials.

So, for example, when an oil is spoken of as having a viscosity of 500 secs. Saybolt at 100° F., this means that at a uniform temperature of 100° F., it will take 500 secs. for 60 cc. of the oil in question to flow through the viscosimeter orifice.

Both these methods measure viscosity empirically. Kinematic viscosity also can be measured directly. The Kinematic Viscosimeter is used chiefly in laboratory work where more accurate data is desirable for calculating viscosity index.

The Universal viscosity scale, or the Kinematic in centistokes, is generally used to designate the viscosity of lubricating oils, the standard temperatures of test being 100, 130 and 210 degrees Fahr. The Furol viscosity scale is generally used for fuel oils or other oils of similar viscosity at standard temperatures of 77, 122 and 212 degrees Fahr., or for asphalts at higher temperatures. The only difference between these machines is in the diameter of the outlet tube or orifice, the Furol tube being the larger, to speed up flow of more viscous oils. The rate of flow through the Furol device is about ten times faster than would be the Saybolt machine, as a result, a numerical reading by the Furol Instrument would be approximately one tenth as great as shown by the Saybolt machine for the same oil.

In normal practice 100° F., is standard when dealing with lubricating oils of a viscosity up to about 1000 seconds at that temperature. For more viscous products which are to be used at higher temperatures, such as light gear lubricants, aircraft engine or steam cylinder oils, 210° F., is preferred. The obvious advantage in raising the temperature of test with such products is to decrease the time element involved and expedite the actual procedure of testing. The viscosity determination at that temperature is also closer to the viscosity to be expected in use since most heavy oils are used at relatively high temperatures.

Significance of Results

According to the American Society for Testing Materials *"the significance of viscosity depends upon the purpose for which the oil is used."

"For lubricating oils viscosity is the most important single property. In a bearing operating properly, with a fluid film separating the surfaces, the viscosity of the oil at the operating temperature is the property which determines the bearing friction, heat generation, and the rate of flow under given conditions of load, speed and bearing design. The oil should be viscous enough to maintain a fluid film between the bearing surfaces, in spite of the pressure tending to squeeze it out. While a reasonable factor of safety is essential, excessive viscosity means unnecessary friction and heat generation. Since the rate of change of viscosity with temperature varies with different oils, viscosity tests should in general be made at that standard temperature which approximates most closely the temperature of use."

*The Significance of Tests of Petroleum Products—Report of Committee D-2 of the A.S.T.M., April, 1943 pp. 46-47.

Value of the Viscosity-Temperature Chart

Wherever operating temperatures may be abnormal, prediction of the approximate viscosity at the prevailing temperatures of use will be of distinct aid in the selection of lubricants which will carry the prevailing loads with the minimum of power consumption. This can be accomplished by use of the A.S.T.M. viscosity-temperature chart. With such a chart it is possible to estimate the approximate operating viscosity of any particular grade of oil over a temperature range from −30° F., to 450° F., by knowing the viscosity at any two points, such as 100 and 210 degrees F.

In considering extreme temperatures, however, we must remember that viscosity values are more academic than practical. At −30° F., the viscosity of all ordinary oils runs up into the tens of thousands or even millions of seconds Saybolt; at this temperature most oils have other limiting characteristics that are more important than the theoretical viscosity. It must also be kept in mind that, at extremely low temperatures, a difference of 5° F. may change the apparent viscosity almost 50 per cent. Along this same line of thought, but conversely, when viscosities at temperatures around 450° F. are concerned, they mean little from a lubricating standpoint. For instance, an oil to have a viscosity of 40 seconds at 450° F. would have to have a viscosity at 100° F. of tens of thousands of seconds in order to meet this requirement, which would render it impracticable for use in any ordinary machinery.

VISCOSITY INDEX

As we have noted above, viscosity can be measured in the laboratory at more than one standard temperature, i.e., 100, 130 or 210° F. During early studies on viscosity, it was observed that different lubricating oils changed in viscosity at different rates as the temperature was varied. Two oils might have the same viscosity at 210° F. and widely divergent viscosities at 100° F. The converse is obviously also true. To define the viscosity temperature characteristics of oils it became the custom to list the

VISCOSITY COMPARISON CHART

SAYBOLT UNIVERSAL VISCOSITY*, SECONDS AT 100° F.	KINEMATIC VISCOSITY, CENTISTOKES AT 100° F.	REDWOOD NO. 1 VISCOSITY, REDWOOD SECONDS AT 100° F.	ENGLER VISCOSITY, DEGREES ENGLER AT 100° F.
32.6	2.0	30.5	1.14
34	2.4	31.5	1.17
36	3.0	33.0	1.22
38	3.6	34.6	1.27
40	4.3	36.3	1.33
42	4.9	37.9	1.39
44	5.5	39.5	1.44
46	6.2	41.3	1.50
48	6.8	42.9	1.55
50	7.4	44.5	1.60
55	8.9	48.7	1.74
60	10.3	52.7	1.86
65	11.7	57.1	1.99
70	13.1	61.5	2.13
75	14.4	65.8	2.26
80	15.7	70.2	2.40
85	17.0	74.7	2.54
90	18.2	79.0	2.67
95	19.4	83.4	2.80
100	20.6	87.8	2.94
110	22.9	96.5	3.20
120	25.3	105.5	3.49
130	27.5	114.1	3.76
140	29.8	123.2	4.04
160	34.3	140.9	4.61
180	38.7	158.5	5.17
200	43.2	176.5	5.75
225	48.6	198.2	6.44
250	54.0	220.0	7.11
300	64.9	264.1	8.54
350	75.8	307.1	9.97
400	86.6	350.9	11.39
450	97.4	394.8	12.82
500	108.3	438.7	14.24
550	119.1	482.5	15.66
600	129.9	526.4	17.09
650	140.7	570.2	18.51
700	151.6	614.1	19.94
800	173.2	701.8	22.78
900	194.9	789.6	25.63
1000	216.5	877.3	28.48
1500	324.8	1316.0	42.72
2000	433.0	1754.6	56.96
2500	541.3	2193.3	71.20

*There is no maximum limit to viscosity to be measured by the Saybolt Universal Viscosimeter but, in general, liquids having an outflow time in the order of 1000 seconds and higher, Saybolt Universal, are tested by means of the Saybolt Furol Viscosimeter. The outflow time of the Furol instrument is approximately one-tenth of the Universal. The word "Furol" is a contraction of the phrase "fuel and road oils".

viscosity of these products at two temperatures, usually at 100 and 210° F. It was not easy, however, to compare the viscosity temperature characteristics of oils which did not have the *same* numerical values at one of the test temperatures. For purposes of simplifying such comparisons, the viscosity index system was developed by Dean and Davis working in the research laboratories of the Standard Oil Development Co. in the late twenties.*

How Viscosity Index Is Determined

The original viscosity index table was set up by arbitrarily assigning a viscosity index of 0 to a sample of naphthenic oil made from a coastal crude and a viscosity index of 100 to a sample of paraffinic oil made from Pennsylvania crude. Oils having viscosity temperature characteristics intermediate between these samples were assigned intermediate viscosity indices. By reference to the V.I. Table, the viscosity index of an oil is determined on the basis of its viscosity at 100° F. and 210° F.

0 to 100 Not the Confining Limits

It is a common misconception that lubricating oils cannot have viscosity indices outside of the 0 to 100 range. As a matter of fact, certain oils have viscosity indices well below 0 and straight mineral oils have been prepared with viscosity indices as high as 150. Furthermore, oils containing "viscosity index improvers" have been formulated with viscosity indices as high as 300. Such high viscosity index products are only considered necessary where extreme ranges of temperature are encountered in service such as in military aircraft hydraulic systems where temperatures may range from −80 to 150° F.

Significance of Viscosity Index

The V.I. Table was originally developed as a simple means of expressing changes of viscosity with increasing or decreasing temperature. This original conception has been at times obscured by claims that high viscosity index was an indication that a lubricating oil possessed the most desirable lubricating characteristics. Actually, the viscosity index of a lubricating oil is only significant when the viscosity of the oil at widely separated temperatures is related to the ability of that oil to function as a lubricant. An outstanding example of a condition where the viscosity at two widely separated temperatures is significant is in the winter operation of automotive engines. In this case, the viscosity of the oil at atmospheric temperature will affect the starting characteristics of the engine and the viscosity of the oil at the operating temperature will affect the running characteristics of the engine.

A Saybolt Universal Viscosity of 40,000 seconds is generally considered the maximum viscosity permissible to enable satisfactory starting of an automotive engine.

A comparison of temperatures at which oils of the different SAE classifications, having identical viscosities at 210° F. and V.I. differing by 15 units, will start are shown in Table I, page 44.

HOW TO USE THE VISCOSITY BLENDING CHART

In order to adapt the viscosity-temperature chart as a blending guide, we have used that portion of the chart between 0° F. and 100° F., covering a viscosity range of 37 to 3000 — the range ordinarily encountered. Let the left vertical represent 100% of the lighter oil, or Oil B. Let the right vertical, represent 100% of the heavier oil, or Oil A. By plotting the known viscosities of any two oils at the same temperature on these respective verticals and connecting them by a straight line, points along this connecting diagonal show the viscosities at the given temperature according to the proportion of the respective oils in the blend.

Example 1

How much oil of 50 SSU at 100° F. (Oil B.) must be blended with a 200 SSU at 100° F. (Oil A) to give a 100 second viscosity oil?

Draw a line between the 50 and 200 viscosity points on the respective zero lines. Note where this line crosses the 100 viscosity horizontal. The answer is 36% of 50 viscosity oil (Oil B) and 64% of 200 viscosity oil (Oil A).

Example 2

What is the viscosity of a blend of 20% of a 40 SSU at 100° F. oil (Oil B), and 80% of a 150 SSU at 100° F. oil (Oil A).

Draw a line connecting 40 viscosity on the Oil B line, and 150 viscosity on the Oil A line. This line crosses the 80% line (Oil A) at 94, indicating 94 SSU at 100° F., to be the viscosity of the desired blend.

For stationary engines, gas, diesel, or gasoline, operated inside buildings where atmospheric temperature variations are not excessive, the viscosity at the starting temperature is relatively unimportant. Here the main concern is the viscosity at the operating temperature.

Relation to Other Oil Characteristics

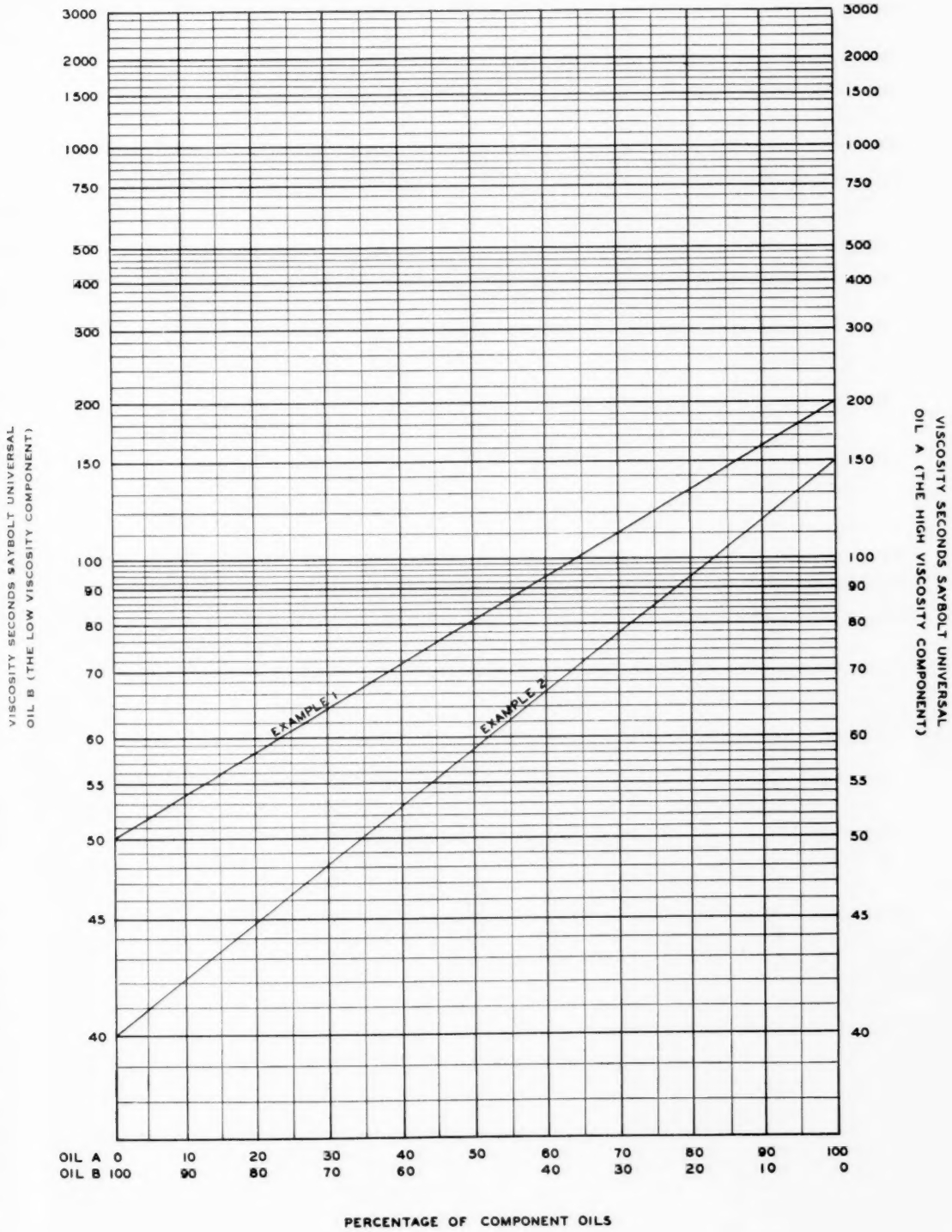
Viscosity index by itself is not indicative of the oxidation stability of a lubricating oil. Claims have often been made that high V.I. oils show outstanding resistance to oxidation. The method of refining is the all important factor in connection with oxidation stability of a straight mineral oil, and modern refinery procedure can produce oils of comparable stability regardless of the viscosity index comparison.

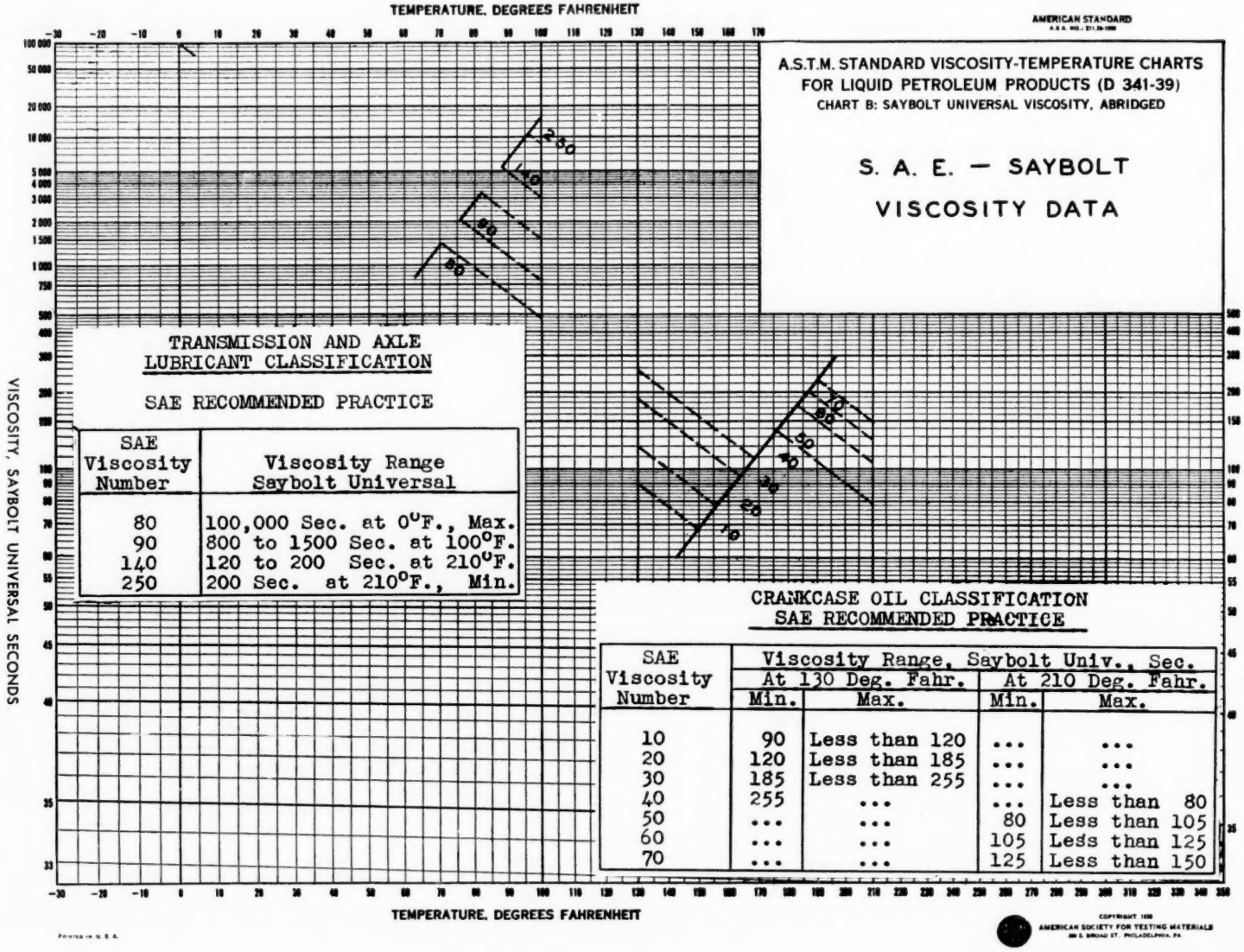
Relation of Viscosity to Pressure

Another effect which must be taken into consid-

*The original description of the Dean and Davis system of viscosity index was published in Chemical and Metallurgical Engineering, Vol. 36, p. 618 (1929) . . .

VISCOSITY BLENDING CHART





TRANSMISSION AND AXLE
LUBRICANT CLASSIFICATION

SAE RECOMMENDED PRACTICE

SAE Viscosity Number	Viscosity Range Saybolt Universal
80	100,000 Sec. at 0°F., Max.
90	800 to 1500 Sec. at 100°F.
140	120 to 200 Sec. at 210°F.
250	200 Sec. at 210°F., Min.

CRANKCASE OIL CLASSIFICATION
SAE RECOMMENDED PRACTICE

SAE Viscosity Number	Viscosity Range, Saybolt Univ., Sec.			
	At 130 Deg. Fahr.		At 210 Deg. Fahr.	
	Min.	Max.	Min.	Max.
10	90	Less than 120	...	...
20	120	Less than 185	...	...
30	185	Less than 255	...	...
40	255	...	...	Less than 80
50	...	...	80	Less than 105
60	...	...	105	Less than 125
70	...	...	125	Less than 150

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ABRIDGED VISCOSITY INDEX TABLE

Viscosity at 100° F. Saybolt Universal Seconds	Viscosity at 210° F., Saybolt Universal Seconds																				
	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145
150	130																				
200	73	133																			
250	17	103	135																		
300		73	115	135																	
350		43	96	121	135																
400		13	76	107	125	135															
450			57	93	114	127	135														
500			37	79	103	118	128	135													
550			18	65	92	109	121	129	135	139											
600			0	51	81	101	114	123	129	134	138										
650				37	71	92	107	117	124	130	134	137	139								
700				23	60	83	100	111	119	125	130	134	136	139							
750				9	49	75	92	105	114	121	126	130	133	136	138	139					
800					38	66	85	99	109	116	122	127	130	133	135	137	138				
850					27	57	78	93	104	112	118	123	127	130	133	135	136	138	139		
900					16	49	71	87	99	108	115	120	124	128	130	132	134	136	137	138	139
950					6	40	64	81	94	103	111	116	121	125	128	130	132	134	135	136	137
1000						31	57	75	88	99	107	113	118	122	125	128	130	132	134	135	136
1050						23	50	69	83	94	103	110	115	119	123	126	128	130	132	133	134
1100						14	43	63	78	90	99	106	112	117	120	123	126	128	130	132	133
1150						5	35	57	73	85	95	103	109	114	118	121	124	126	128	130	131
1200							28	51	68	81	91	99	106	111	115	119	122	124	127	128	130
1250							21	45	63	77	87	96	103	108	113	117	120	123	125	127	128
1300							14	39	58	72	83	92	100	106	110	114	118	121	123	125	127
1350							7	33	53	68	80	89	97	103	108	112	116	119	121	124	125
1400							0	27	48	63	76	86	93	100	105	110	114	117	120	122	124
1450								21	42	59	72	82	90	97	103	108	112	115	118	120	122
1500								15	37	54	68	79	87	95	100	105	110	113	116	119	121
1550								9	32	50	64	75	84	92	98	103	108	111	114	117	119
1600								3	27	46	60	72	81	89	96	101	105	109	113	116	118
1650									22	41	56	68	78	86	93	99	103	107	111	114	116
1700									17	37	52	65	75	84	91	96	101	106	109	112	115
1750									12	32	49	61	72	81	88	94	99	104	107	111	114
1800									7	28	45	58	69	78	86	92	97	102	106	109	112
1850									1	23	41	55	66	75	83	90	95	100	104	108	111
1900										19	37	51	63	73	81	87	93	98	102	106	109
1950										15	33	48	60	70	78	85	91	96	101	104	108
2000										10	29	44	57	67	76	83	89	94	99	103	106
2100										1	21	37	51	62	71	78	85	90	95	99	103
2200											14	31	45	56	66	74	81	87	92	96	100
2300											6	24	38	51	61	69	77	83	88	93	97
2400												17	32	45	56	65	73	79	85	90	94
2500												10	26	40	51	60	68	75	81	87	91
2600												3	20	34	46	56	64	72	78	83	88
2700													14	29	41	51	60	68	74	80	85
2800													8	23	36	47	56	64	71	77	82
2900													2	18	31	42	52	60	68	74	79
3000														12	26	38	48	57	64	71	76
3200														1	16	29	40	49	57	64	70
3400															6	20	31	41	50	58	64
3600																11	23	34	43	51	59
3800																2	15	26	36	45	53
4000																	7	19	29	39	47
4200																		11	22	32	41
4400																		4	15	26	35
4600																			9	19	29
4800																			2	13	23

The difficulty of obtaining accurate Saybolt Universal values for viscosities lower than 45 seconds at 210° F. is so great that the viscosity index table is not extended below that limit. The accuracy of the viscosity index may be increased by the use of the Kinematic Viscosimeter at 210° F. for oils having viscosities between 40 and 75 Saybolt Universal seconds at 210° F., since the conversion of Kinematic viscosity in this range at 210° F. to Saybolt viscosity is more reliable than the actual Saybolt determination. To show which viscosity index values are in this critical range, dotted lines have been used to set it apart from the rest of the table.

eration when determining the actual operating viscosity of an oil within the engine is that of operating pressure. The tendency of low V.I. oils to thin out more than high V.I. oils as temperature increases is greatly offset by the effect of pressure on viscosity.

Table No. 3 shows that under pressure sufficient to perhaps cause bearing failure, the low V.I. oil is actually more viscous in the engine due to the influence of pressure. This refutes the idea that viscosity index is the only characteristic that must be considered as a measure of the load carrying ability of an oil. Where very high load carrying capacity is desirable, it is obtained by means of additives.

TABLE NO. 1

S.A.E. Classification	10	20	30	40	50
Min. temp. for 100 V.I.	−21° F.	−5° F.	+3° F.	+14° F.	+21° F.
" " " 85 V.I.	−17° F.	0° F.	+8° F.	+20° F.	+28° F.
Difference	4° F.	5° F.	5° F.	6° F.	7° F.

The difference in viscosity at the operating temperature, however, would be negligible, as shown by Table No. 2 below:

TABLE NO. 2

SAE Classification	Viscosity Index	Saybolt Viscosity At 100° F.	Saybolt Viscosity At 210° F.
SAE 10	100	170	44.5
SAE 10	85	170	43.8
SAE 20	100	350	55.7
SAE 20	85	350	53.6
SAE 30	100	520	65.7
SAE 30	85	520	62.0
SAE 40	100	850	83.0
SAE 40	85	850	77.1

TABLE NO. 3

EFFECT OF PRESSURE ON VISCOSITY

Viscosity index	103	−20
Saybolt Vis. at 210° F.—atmos. pressure	62	54
Saybolt Vis. at 210° F.—4000 lbs./sq. in.	86	109

DIRECTIONS FOR USE OF VISCOSIMETER CONVERSION CHART

OBJECT: To find the viscosity reading of a particular oil on any of the standard viscosimeters when its reading on one of the viscosimeters has been determined by experiment ***at the same temperature.***

SCALES: There are two sets of scales which **must not be confused** with each other.

X: The scales at bottom and left hand side go together. They are the ones regularly used in practice applying to all ordinary oils.

NOTE: There are two lines of scales at the bottom:

(a) The **lower** scale applying only to **degrees**-Engler.

(b) The **upper** scale applying to all other readings, including Engler-**time.**

In simply changing from one viscosimeter to another the scales at left and right are not used.

The scales at top must never be used in connection with those at the bottom.

Y: The scales at top and on right hand side go together. They are rarely used, applying only to very viscous products beyond range of other scales.

APPLICATION OF CHARTS: X: For ordinary cases.

GIVEN: Saybolt Universal Viscosity = 120".

DESIRED: Case (a) Barbey reading.
Case (b) Engler-degree reading.

PROCEDURE: Find point on bottom scales for Saybolt Universal corresponding to 120" (A).

Follow up vertically to curve marked Saybolt Universal (the known instrument) (B).

(a) To get Barbey reading: Follow horizontally to curve marked Barbey (C).
Drop down to bottom scale for Barbey and read (D). Reading = 208°.

(b) To get Engler-Degree reading: Follow horizontally to curve marked Degrees-Engler (E).
Drop down to lower of the two bottom scales for Engler-Degrees and read (F). Reading = 3.60°.
i. e., 120" Saybolt = Barbey 208° = Engler 3.60°.

Y: For very viscous fluids beyond range of other scales:

GIVEN: Engler-Degrees = 1100°.

DESIRED: Saybolt Furol reading.

PROCEDURE: Find point on upper scales under Degrees-Engler corresponding to 1100° (G).

Follow vertically down to Degrees-Engler curve (H).

Follow horizontally to curve marked Furol (J).

Rise, vertically to scales under Furol and read (K). Reading = 3800".

i. e., 1100° Engler = 3800" Furol.

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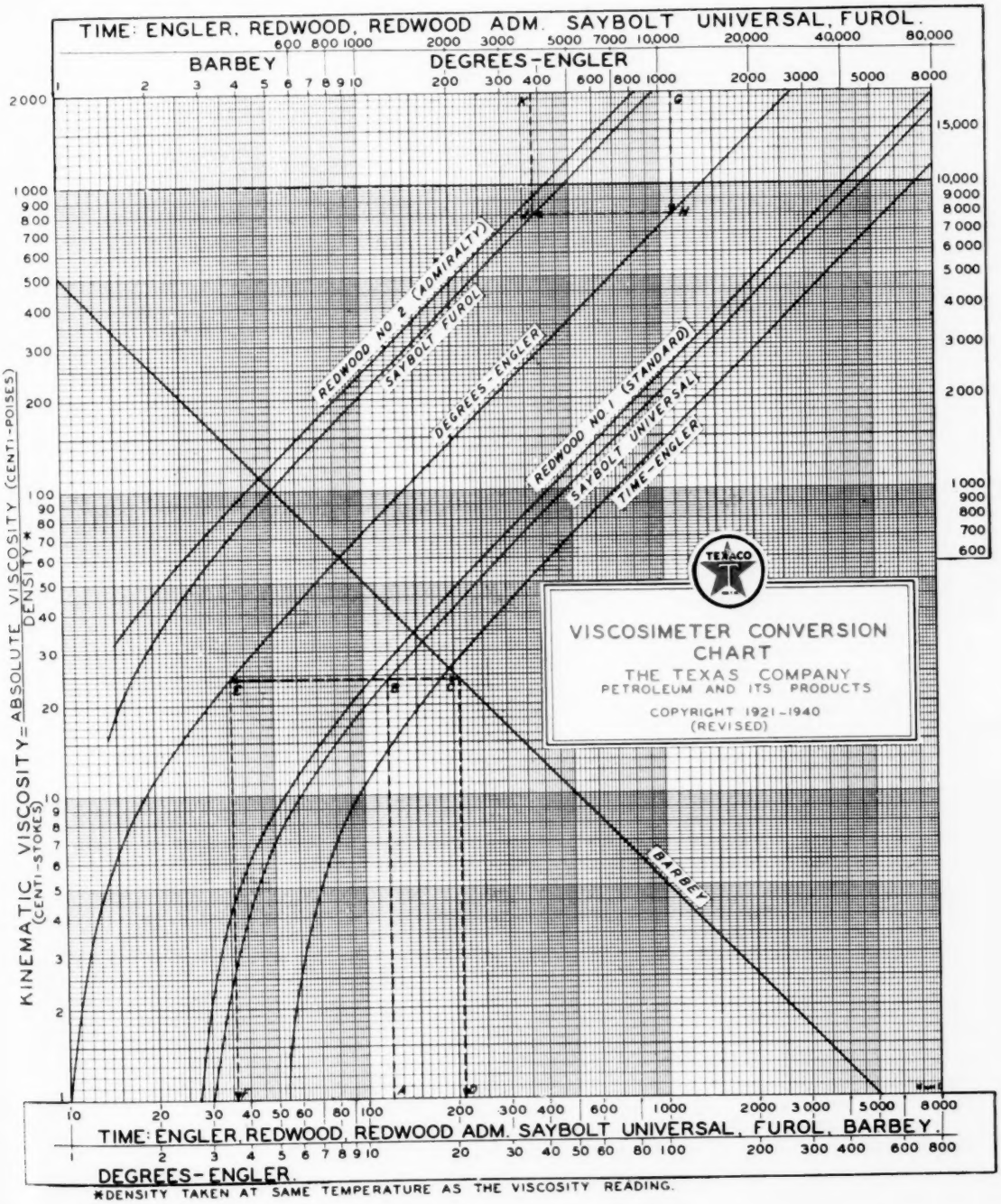
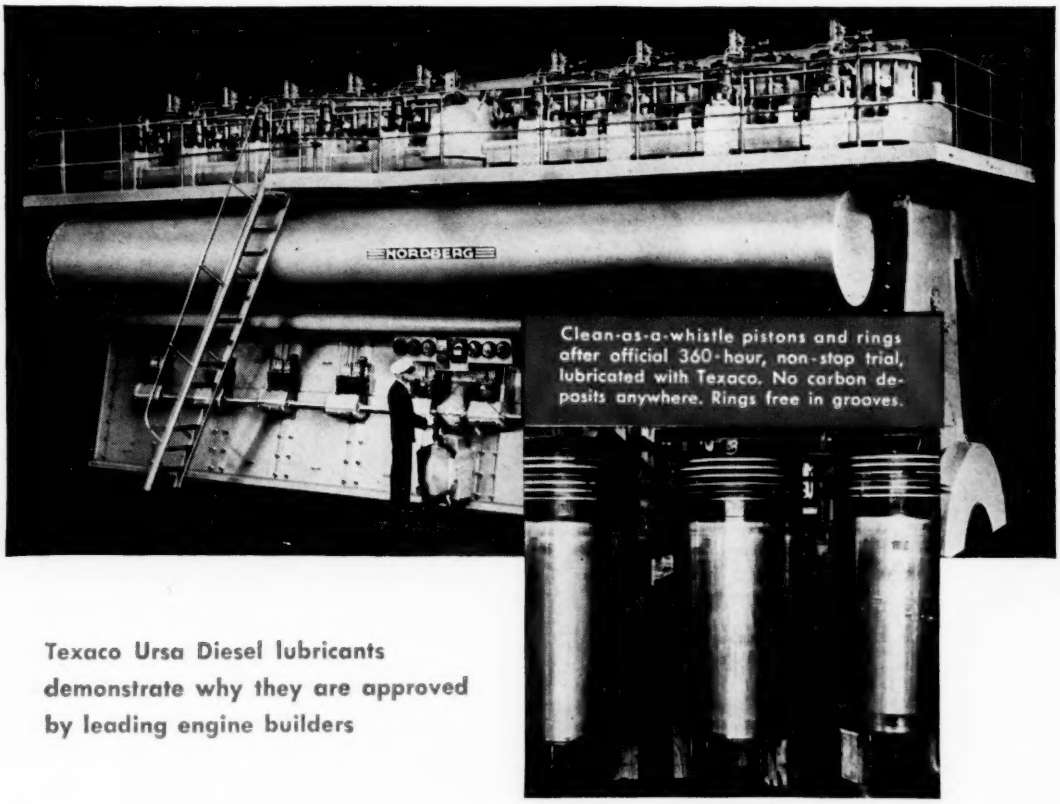


*DENSITY TAKEN AT SAME TEMPERATURE AS THE VISCOSITY READING.

TESTING... America's Most Powerful Single Acting Diesel



Clean-as-a-whistle pistons and rings after official 360-hour, non-stop trial, lubricated with Texaco. No carbon deposits anywhere. Rings free in grooves.

Texaco Ursa Diesel lubricants demonstrate why they are approved by leading engine builders

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